Discovery of Non Thermal X-Rays from the Northwest Shell of the New SNR RX J1713.7-3946: The Second SN1006 ?

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Abstract

We report ASCA results of a featureless X-ray spectrum from RX J1713.7−3946, a new shell-like SNR discovered with the ROSAT all sky survey. The northwest part of RX J1713.7−3946 was in the field of the ASCA Galactic Plane Survey Project and was found to exhibit a shell-like structure. The spectrum, however shows neither line emission nor any signature of a thermal origin. Instead, a power-law model with a photon index of 2.4-2.5 gives reasonable fit to the spectrum, suggesting a non-thermal origin. Together with the similarity to SN1006, we propose that RX J1713.7−3946 is the second example, after SN1006, of a synchrotron X-ray radiation from a shell of SNRs. Since the synchrotron X-rays suggest existence of extremely high energy charged particles in the SNR shell, our discovery should have strong impact on the origin of the cosmic X-rays.

Key words: ISM: individual objects (RX J1713.7−3946) — ISM: supernova remnants —Radiation mechanism —X-rays: sources —X-rays: spectra

1. Introduction

X-rays from shell-like supernova remnants (SNRs) are generally attributable to a thin thermal plasma shock-heated by an energetic explosion of a progenitor, while additional hard X-rays with a power-law spectrum have been found in some of the shell-like SNRs. The most outstanding and extreme example of a non-thermal emission from a shell is found in SN1006 (Koyama et al. 1995). The power-law X-ray spectrum extending smoothly to the radio band leads us to suspect that the X-rays are due to synchrotron radiation of extremely high energy electrons reaching to about 100 TeV (Koyama et al. 1995). Similar, but somehow less compelling example for such synchrotron X-ray radiation is found in IC443; the hard X-ray image shows an arc structure surrounding a center-filled thermal emission (Keohane et al. 1997).

These non-thermal emissions from SNR shells are potentially important with the conjecture of a possible origin of cosmic ray production and acceleration. The electro-magnetic radiation from high energy charged particles has a wide band spectrum from radio to gamma-rays, with radiation processes such as synchrotron, Bremsstrahlung, inverse-Compton scattering and nuclear reaction. However, such radiations from SNRs with no central pulsar have been scarcely observed, except for the synchrotron emission from electrons of energy below GeV (for radio SNRs). If the hard X-ray com-

ponents found in SN1006 and IC443 really come from non-thermal electrons accelerated by a shock wave, protons should also be accelerated to the same energy, providing a strong support for the cosmic-ray acceleration in shell-like SNRs, possibly near to the "knee energy" (Reynolds 1996). Consequently, the most urgent subjects would be to find further evidence for a non-thermal emission from other shell-like SNRs and to study whether the non-thermal emission is universal or not. Previous non-imaging instruments or soft X-ray imaging satellites have been unsuccessful for these studies. A breakthrough may be provided by the wide X-ray band imaging spectroscopy, like ASCA, as was already demonstrated with two cases; SN1006 and IC 443.

Pfeffermann and Aschenbach (1996; here and after PA96) discovered a shell-like SNR RX J1713.7−3946 with the ROSAT all sky survey in the Constellation Scorpius with the approximate center at R.A.(2000) = 17^h13^m42, Dec.(2000) = $−39°.46'27''$ (hence named as RX J1713.7-3946). The X-ray image shows a slightly elliptical of a maximum extent of $70'$, with an enhanced emission at the northwest rim. Thus they claimed this SNR as a shell-like SNR. A composite type of shell-like plus synchrotron nebula around a putative pulsar is also possible, because they found unidentified point-like sources at the center of the remnant.

This paper reports a peculiar X-ray spectrum from the bright northwest shell; unlike the shell-like appearance it shows an X-ray spectrum with no significant emission line. Accordingly, we suggest this SNR to be another clear example, after SN1006, of a non-thermal emission from shell-like SNRs.

2. Observations

The ASCA Galactic Plane Survey Project (here and after AGPSP) has started from the AO4 period, and is planed to cover all the galactic inner disk ($|l| < 45°$ and $|b| < 0°.8$) with successive pointing observations of about 10 ksec exposure in a region of $50'$ diameter each, and will be continued during the full ASCA mission life of several years. One major objective of the AGPSP is, utilizing the wide and high energy band (up to 10 keV) X-ray imaging capability and high spectral resolving power of ASCA, to search for possible X-ray SNRs in the galactic inner disk, which would be either catalogued radio SNRs or completely new SNRs.

The survey of the AO4 phase was made in 1996 August-September, covered the region of l =342°.2 − 346°.7, 347°.2 − 351°.7 and l=1°.0 − 5°.5 along b=0° of about $50'$ width. Some of the fields covered a fraction of the new SNR RX J1713.7−3946, the region of the bright northwest rim. These observations were made with two CCD cameras (designated SIS0 and SIS1) and two gas-imaging spectrometers (GIS 2 and GIS 3) at foci of 4 thin-foil X-ray mirrors (XRT) on board the ASCA satellite. Details of the instruments are respectively given in Ohashi et al. (1996) and Makishima et al. (1996), Burke et al. (1994), and Serlemitsos et al. (1995), for GISs, SISs and XRTs. While, a general description of ASCA is given in Tanaka et al. (1994).

The SIS data were obtained in the 4-CCD mode covering the field of view of $22' \times 22'$ square, while the GIS data were taken in the normal PH mode with a circular field of $25'$ radius. We excluded the data obtained at the South Atlantic Anomaly (SAA), the earth occultation, the high-background regions at low geomagnetic cut-off rigidities of < 6 GeV/c. For the GIS data, we applied a rise-time discrimination technique to reject particle events. The data with the elevation angle from the earth rim of $< 5°$ are also excluded in GIS, while for the SIS data screening criterion are $< 10°$ and $< 20°$(SIS1) and $< 25°$(SIS0) from the night and day earth rims, respectively.

The data quality, after about 3 years on orbit operation, were exhibited significant degradation due mainly to the particle irradiation (Dotani et al. 1995). The most serious problem for the present SNR observation is the increase of pixel-to-pixel fluctuation of the dark current, which makes the energy resolution worse. In order to estimate and subtract the pixel-dependent dark current, we intentionally took the full pixel data (the frame mode data) during the normal operation, and estimated the dark frame level for the relevant CCD pixels. This procedure, called the RDD (Residual Dark Distribution)-correction was found to restore the energy resolution significantly; improved from 210 eV to 110 eV of FWHM at 1.86 keV in the 4 CCD mode. Further details of the long term performance of the CCD in orbit and the RDD-correction technique are given by Dotani et al. (1995, 1997).

3. Analysis and Results

Figure 1 shows the GIS mosaic image of 4-successive pointings near the northwest part of RX J1713.7−3946. In the figure, we see three X-ray sources: point-like objects at northeast and southwest and a diffuse emission with shape of crescent reversed. The first point source is a newly discovered transient and the other is 1RXS J170849.0-400910, from which we found a coherent pulsation of about 11-s (Sugizaki et al. 1997). Details of these source will be given in separate papers. The center diffuse source comes near the ROSAT new SNR RX J1713.7−3946. By comparing with the full image of RX J1713.7−3946 of ROSAT observation (PA96), we conclude that the diffuse structure is certainly a part of RX J1713.7−3946, the bright northwest rim. Although the SIS field of view is smaller than GIS, we also found a diffuse excess emission from the northwest shell.

We extracted the GIS and SIS spectra from the shell-like region, and subtracted the nearby background sky. The northwest shell is located in the galactic ridge region, which exhibits an enhanced thin thermal emission, hence the background subtraction should be particularly careful. Kaneda (1997) and Kaneda et al. (1997) reported the Galactic ridge X-rays observed with ASCA typically show two temperature components: the soft (about 0.8 keV) with scale height of about $3°$ and the hard (7 keV) with smaller scale height of $0°.5$. The center positions of the background regions we took, are nearly the same distance from the galactic plane as that of the center of the shell. Therefore the latitude dependence of the Galactic ridge emission would be canceled in the background subtraction. Furthermore the estimated background flux is about 6×10^{-4} counts s^{-1} arcmin^{-2} GIS^{-1} in the 0.7-10 keV band, which is 20 % of the mean surface density of the northwest rim of 3.2×10^{-3} counts s^{-1} arcmin^{-2} GIS^{-1}. The spatial variation of the Galactic ridge emission found by Kaneda (1997) is less than a few 10 % near the source position. Therefore a systematic error of the background subtraction, attributable to possible uncertainty of the galactic diffuse emission, would be well below a few % of the total source flux, hence we ignore this error.

Figure 2 shows the background subtracted SIS and GIS spectra. Since no significant line is found in the spectra, we tried to set upper limits of the line equivalent widths (EWs) at 1.86, 2.46 and 6.7 keV, which respectively correspond to He-like Si, S and Fe lines and are expected to be major lines in a plasma of a few keV temperature. The 90 % upper limit of the EWs of Si, S and Fe lines are respectively, 16, 35 and 82 eV for the GIS spectra, and 10, 12 and 186 eV for the SIS spectra. These values are nearly to or less than 10 % of those found in Cas A: 0.4-0.6, 0.4-0.5, 0.6-1.3 keV of EW, for Si, S and Fe, respectively (Holt et al. 1994). For a further investigation, we fitted the spectrum to a thin thermal model (MEKA model) with abundances varying collectively. Although GIS spectra do not reject (90 % confidence), the SIS spectra firmly reject the thin thermal model with more than 99.9 % confidence level (reduced χ^2 of 1.45 for 179 d.o.f.). For a comparison and discussion, we list the best-fit parameter values in table 1. Small differences of the best-fit parameters between the SIS and GIS spectra is mainly due to the difference of the regions from which we have made the spectra; the larger area in GIS than in SIS, although possible calibration errors in GIS and SIS do exist. The small difference, however, is minor for further discussions. From the table, we see that abundances are constrained to be unrealistically small; the 90 % upper limit are only 0.09 and 0.08 of solar for the GIS and SIS spectra, respectively. The plasma temperatures of 3.1 (SIS) - 3.8 (GIS) keV are higher than any other shell-like SNRs; even the youngest shell-like SNR Cas A and

W49B exhibit significantly lower temperatures of about 2 keV (Holt et al. 1994, Fujimoto et al. 1995).

Thus, together with the χ^2-test and no emission line (or extremely low abundances), X-rays from the shell of RX J1713.7$-$3946 can not be attributable to a thin thermal plasma. Accordingly we fit the spectra to a power-law with an interstellar absorption, then found to be acceptable with the best-fit parameters given in table 1. The best-fit models convolved with the detector responses are also shown in figure 2.

4. Discussion

PA96 divided the ROSAT data from RX J1713.7$-$3946 in several regions, and found that the spectra, on average, can be fitted with a thin thermal model of two cases; one is a high temperature plasma emission of averaged value of kT = 4.8 keV, with position-dependent absorptions of $N_H = (3\text{-}12) \times 10^{21}$ H cm^{-2}, and the other is lower temperature plasma of kT = 0.5 keV with larger absorptions of $N_H = (1.4\text{-}2) \times 10^{22}$ H cm^{-2}. With the high temperature model, N_H at the northwest rim is found to be $(6.2^+_1) \times 10^{21}$ H cm^{-2}, in good agreement with a thin thermal fit of ASCA data of $N_H = (4.8^+_- 0.4) \times 10^{21}$ H cm^{-2} and kT = $3.8^+_- 0.3$ keV. The ROSAT flux after removing the absorption for the high temperature solution, which is now found to be better approximation than that of lower temperature is $F_X = 4.4 \times 10^{-10}$ erg s^{-1}cm^{-2} in the whole SNR. The ASCA flux within the northwest rim is 2×10^{-10} erg s^{-1}cm^{-2} in the 0.5-10 keV band. This value is the same order of the total flux estimated with ROSAT, hence a significant fraction of the X-rays from the SNR would be attributable to the bright northwest rim.

The most important discovery is that the ASCA spectra, unlike the majority of shell like SNRs, have no significant emission line, and can be fitted by a single power-law model. This leads us to suspect that the X-rays from RX J1713.7$-$3946 are dominated by a non-thermal emission from the northwest shell.

Non-thermal emissions have been found in many synchrotron nebulae (e.g. Kawai and Tamura 1996), in which high energy electrons are accelerated by a fast rotating neutron star. However in the northwest shell, we found neither point-like source nor any pulsed signal. These, together with the shell-like appearance, make the synchrotron nebulae scenario unlikely to the northwest shell. Unclassified point sources are found near the SNR center with ROSAT, hence it may still be conceivable that a putative pulsar at the center emits relativistic jets, then a synchrotron nebula located far from the pulsar can be made as is found in the SNR W50 powered by the unique source SS433 (Yamauchi et al. 1994). However, no pulsation is also found from the central point sources. Furthermore the morphology of W50 is, unlike

to RX J1713.7−3946, not shell-like but plume-like shape.

More likely scenario is that RX J1713.7−3946 is the second case, after SN1006, of a shell-like SNR with a non-thermal dominant emission (Koyama et al. 1995). Although the non-thermal X-ray flux is about 3 times larger than that from SN1006, no radio counterpart has been reported on this SNR. This may be partly due to the rather large background radio emission near the Galactic plane, but mainly due to the intrinsic faint radio flux. The faint radio emission indicates that the SNR should be in low density medium like the case of SN1006 lying off the plane. Since RX J1713.7−3946 is located on the Galactic plane, the low density medium means that it is possibly lying in the intergalactic arm.

The global similarity of RX J1713.7−3946 to SN1006 leads us to infer that essentially the same shock acceleration process as the SN1006 shell are going on in the shell of this new SNR(Reynolds 1996). To investigate this scenario, in particular to determine the physical parameters such as the strength of the magnetic field, acceleration age, energy loss rate, and the diffusion time scale of the high energy particles, further observations, not only in the X-ray domain but also the radio and gamma ray bands, are strongly encouraged. These are highly important in the conjecture of the long standing problem of the cosmic ray acceleration and its origin (see e.g. , Koyama et al. 1995, Reynolds 1996).

The age estimation of PA96 based on the assumption of a thin thermal plasma at Sedov phase is found now to be incorrect. Thus the proposal by Wang et al. (1997) that RX J1713.7−3946 is a remnant of a supernova of AD393 appeared in the old Chinese literature become more debatable than before. Suppose that the ($N_{\rm H}$ value of 10 kpc distance along the SNR direction is 6×10^{22} H cm^{-2}, an averaged value to the Galactic center region, we infer that the SNR located at a distance of about 1 kpc, possibly just behind the Sgr-Carina arm. This gives the radius of RX J1713.7−3946 ($70'$ along the major axis) to be about 10 pc, the same size as SN1006. Taking the expansion speed of the SNR to be the largest so far found in young SNRs, or about 10^9 cm s^{-1}, the age is given to be about 1000 yr. This age should be taken as a lower limit, and the real age would be a few thousand years, still leaving a possibility of the AD393 SN origin.

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Table 1: The best-fit parameters of thin thermal (MEKA) and power-law models.

	Temperature (kT)[keV]	N_{H} [10^{21}cm^{-2}]	Abundance	r educed-χ^2(d.o.f)
GIS	$3.8^+_-\ 0.3$	$4.8^+_-\ 0.4$	< 0.09	1.14 (144)
SIS	$3.1^+_-\ 0.2$	$7.4^+_-\ 0.3$	< 0.08	1.45 (179)
	photon index(α)	N_{H} [10^{21}cm^{-2}]		reduced-χ^2(d.o.f)
GIS	$2.4^+_-\ 0.1$	$8.1^+_-\ 0.6$		1.12 (145)
SIS	$2.5^+_-\ 0.1$	$10.1^+_-\ 0.5$		1.23 (180)

∗ Errors are single parameter 90% confidence levels.

† Assuming the solar abundance.

Figure Captions

Figure 1:A mosaic GIS image along the galactic plane near (l, b)= $(347°, 0°)$. The structure of crescent reversed is a part of RX J1713.7−3946 (the northwest rim), the other two point sources are respectively a new transient source (the northeast source) and new X-ray pulsar (the southwest source).

Figure 2:The SIS 0+1 and GIS 2+3 spectra of the northwest rim of RX J1713.7−3946 (crosses) convolved with the detector response. The histograms are the best-fit power law models (see text). Lower panels for each are the data residuals from the best-fit model in units of σ.

Fugure 1:

Figure 2:

G347.5−0.5

G347.5−0.5

SIS0 + SIS1
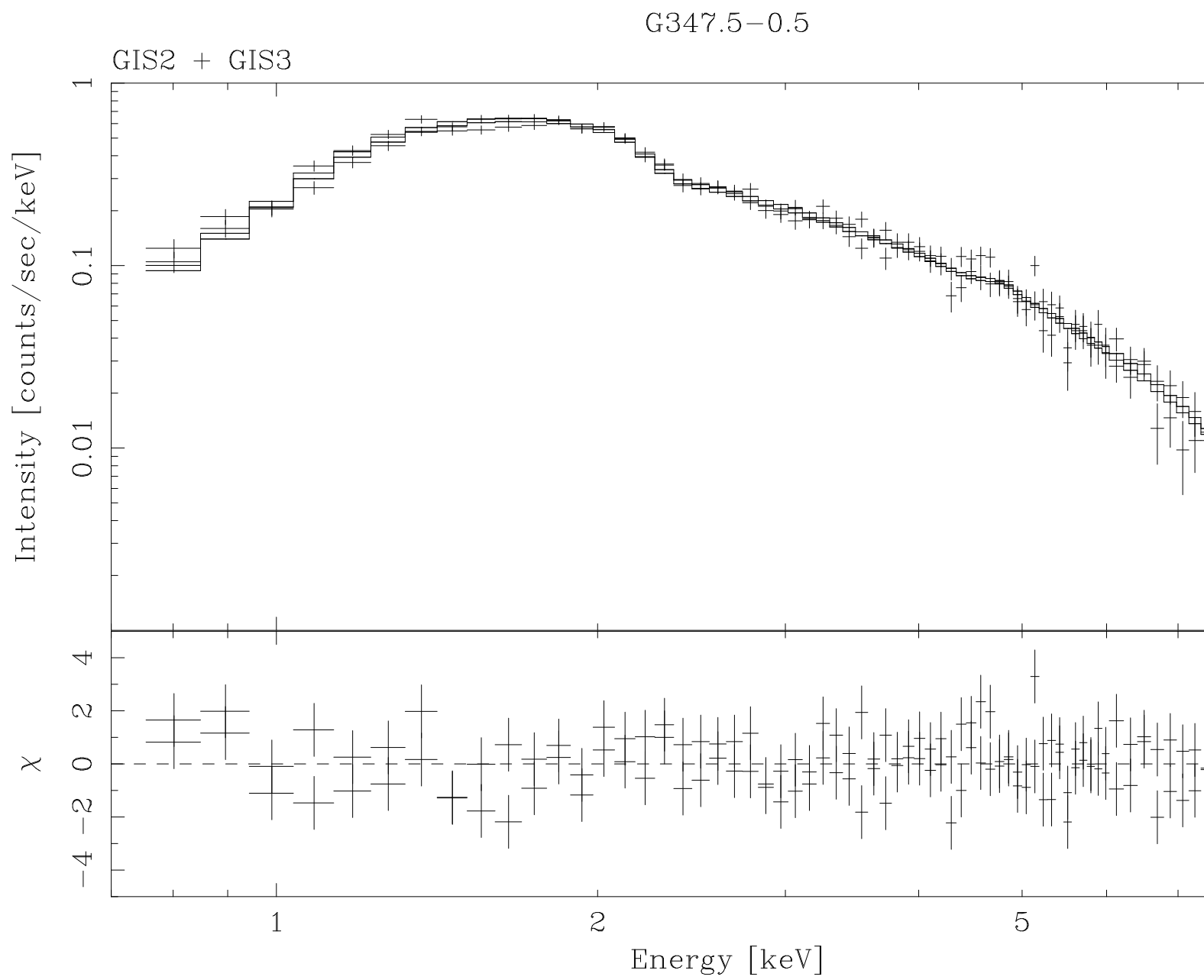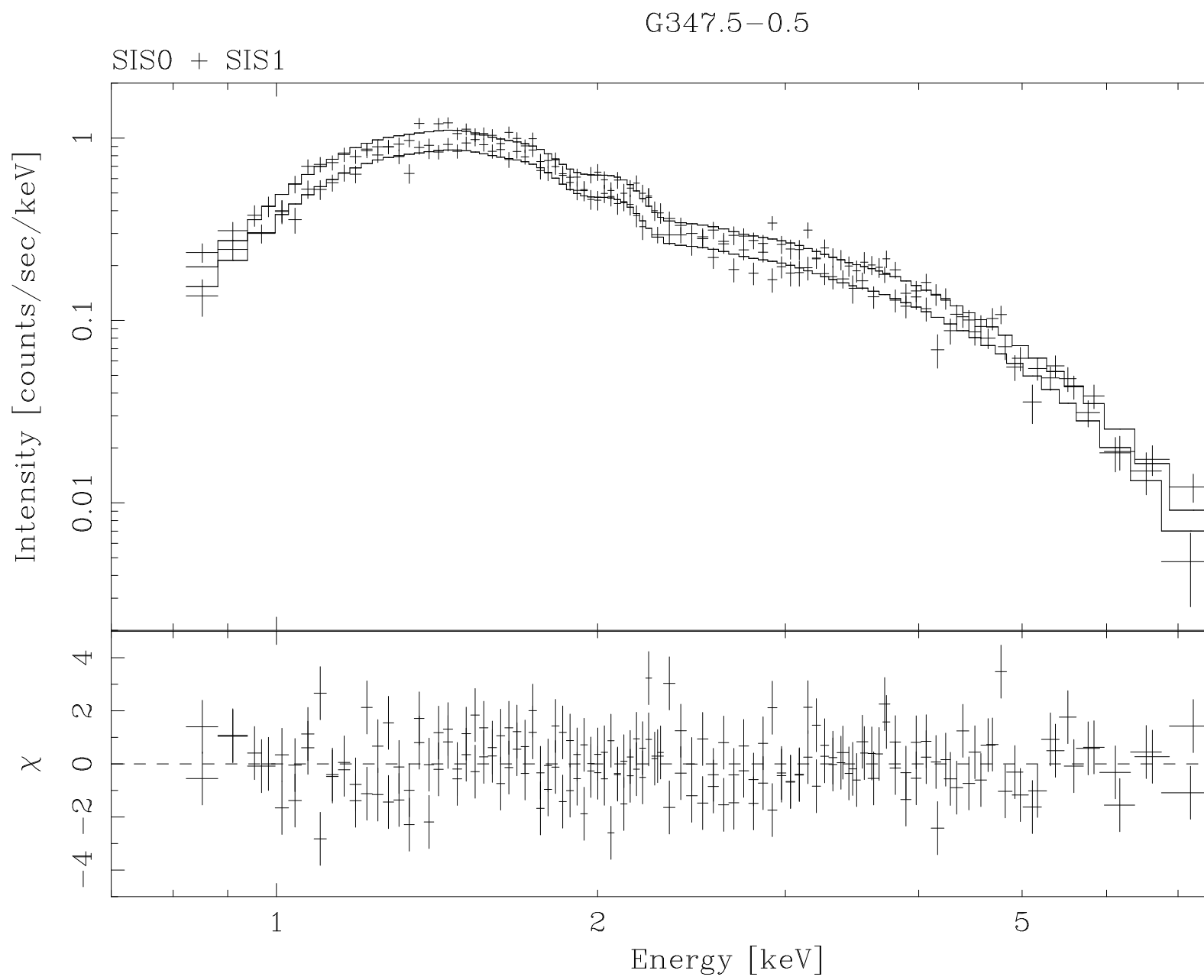
G347.5−0.5

ASCA GIS3   1996 Sep 3   Exposure: 76158 s

17^{h}14^{m}00^s 17^{h}12^{m}00^s 17^{h}10^{m}00^s 17^{h}08^{m}00^s 17^{h}06^{m}00^s

−39°00'00"

−39°30'00"

−40°00'00"

−40°30'00"

Y Pixels

X Pixels